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Apparent Moving Sensation Recognition in Prosthetic Applications

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Abstract

Recent years have seen considerable improvements in state-of-the-art prosthetic devices. Research has recently shifted towards providing sensory information feedback to users of such prostheses. Sensory information is necessary for the seamless integration of these devices with the human body. In this study we look at the possibility to use the "apparent moving sensation" effect as a means of transmitting proprioceptive information, using trans cutaneous electrical stimulation. We applied 5 incremental steps (20%, 40%, 60%, 80%, 100%) on both sides of the spine, in two directions (up, down). An average of 74.56% recognition rate was observed, with only two patterns under the 75% recognition threshold.

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Keywords: Neuroprosthesis; Sensory feedback; Electrical stimulation

1. Introduction

The majority of prosthetic devices do not convey any information regarding their internal or the environmental states to the user. Such an implementation of sensory feedback is however an important aspect for prosthetic devices. If we are to realize the vision of seamless integration of artificial limbs with the human body, we need to improve not only motor control but also sensory feedback to the user. Recent attempts towards providing sensory feedback to prostheses users are commonly utilizing vibrotactors, electrical stimulation, Peltier elements [1] but also novel techniques such as using skin torsion [2] as a feedback mechanism to transmit extro- and proprioceptive information (e.g. heat, pressure, joint angles). As the somatosensory system of the human body is a low to medium bandwidth channel - so not a lot of information can be transmitted through it - one idea towards maximizing transmission efficiency and reducing device complexity is to exploit certain illusions present in the system. One of these illusions is the "apparent moving sensation" [3]. The illusion can be elicited by simultaneously stimulating two places in the body, producing a moving sensation between the stimulation points. This method has been used in rehabilitation applications for quadriplegic patients [4]. The illusion can be generated through either vibrotactors or transcutaneous electrical stimulation on the user's skin. We explore the requirements to transmit a reliable and controllable moving sensation in the lower back with electrical stimulation as it allows for increased control over the sensation generated [4]. In this study we are interested in the capacity of the human body to recognize the direction of the apparent moving sensation, and the stimulation distance.

2. Methodology

We used an electrical stimulator developed at our laboratory by Seps [5], which can produce high frequency stimulation signals. We used self-adhesive, multilayer, hydrogel electrodes (PALS Neurostimulation electrodes, Axelgaard Manufacturing CO., Ltd.). We chose round electrodes with a diameter of 3.2 cm for the best trade-off between a broad voltage stimulation range and small inter-individual performance differences. We decided to use a stimulation

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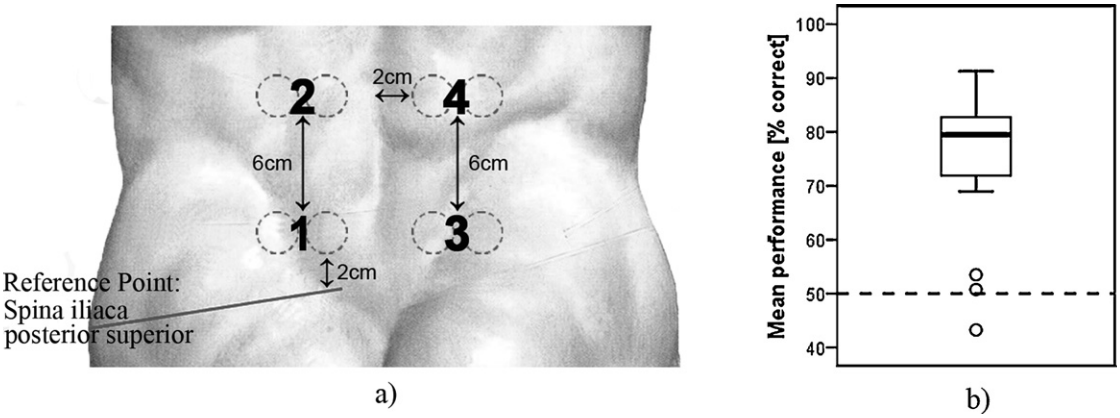

Figure 1. Stimulation setup and results. a) Electrodes placement positions. b) Distribution of the overall performance for all subjects (n=16). Median of 79.50, with quartiles of 83.33 and 70.44. Outliers are presented with a circle. The dashed line represents the minimum performance rate of 50%. The error bars represent the 95% confidence interval.

frequency of 2 kHz, taking advantage of the subthreshold summation [6] to produce depolarization of the nerves. The system was controlled using our own developed software "Vstim" using a PC (Windows XP, Intel Core2 Duo 2.80 GHz, 2 GB RAM). Data was collected from 16 volunteers (3 females, 13 males) with a mean age of 26.75 + 1.002 (range: 20 to 35 years). All subjects gave their informed consent under the approval of the Swiss Ethics Committee. Eight electrodes were placed following the schema in Figure 1(a). To determine the voltage required for a comfortable stimulation, the voltage in the electrodes was gradually incremented from 0 Volts until the person could identify the stimulation. The stimulation voltage was set at a 25% increment from this sensory threshold. In order to ensure a proper measurement of the performance in detecting the moving sensation, all electrode pairs were tested, and differences in the sensation recognition were addressed by adjusting the voltage in individual electrode pairs. The participants had to recognize the difference between 20 stimulation patterns. The patterns were constructed by changing the stimulation intensity (20%, 40%, 60%, 80% and 100%), the direction of the illusion and the position of the stimulation electrodes. All stimulation patterns started from a middle point position in the lower back using a 50% duty rate. To produce the moving sensation the intensity was gradually increased in the targeted electrode pair and decreased accordingly in the complementary electrode pair. The duration of the stimulation depended on the changes in the duty rate. The participants were requested to identify only the direction of the moving sensation using a modified keyboard to express their answer. The experiment was conducted in four sessions, with each session lasting between 3 to 5 min, and a total of 100 trials. A single trial could be terminated by either a preset timer (4 s) or a button press. Between the termination of one trial and the next there was an inter-trial time of 1 s without stimulation; during this time the program would not react to key presses. The participant's responses (key presses) were automatically recorded.

3. Results

Performance was measured as the ratio of correct answers against the number of trials. Subjects with a performance lower than 50% were excluded from further analysis. We used analysis of variance (ANOVA) for repeated measures, with pattern (Duty Rate Change (DRC)), direction (up, down) and stimulation side (right, left) as within-subjects factors. Greenhaus-Geisser corrections were applied on the degree of freedom to adjust for violations of the assumption of sphericity. Further analysis of significant results included post-hoc t-tests. To compare the within subjects factors, paired-samples t-test were used. Data analysis was performed using the statistical program SPSS (Statistical Package for the social sciences, version 17). The mean performance over all patterns, for both directions and both stimulation sides was $\mu = 74.56 \pm 13.90$ (Md 79.50).

Figure 2(b) shows a box plot of the overall performance in detecting the direction of the stimulation. Three subjects were marked as outliers due to their low mean performance. Spearman's correlation test between mean voltage level and mean performance showed no significant correlation, $rs = 0.14$, $p > 0.05$. Data sets were tested on the assumption of normality and homogeneity of variances. Levene's test revealed that homogeneity could be assumed, $F(12) = 1.35$, p

< 0.05. ANOVA for repeated measures (within-subjects factor stimulation side, pattern, and moving direction) showed no significant effect of the stimulation side on performance, neither any effect from stimulation side. The participants presented an almost identical performance in direction recognition regardless of stimulation side (0.12% difference). Stimulation patterns had the only influence on performance.

4. Discussion

By applying electrical stimulation on the lower back using an arrangement of eight electrodes we were able to reproduce the apparent moving sensation. Using a sample of 16 subjects, we found an average recognition rate of 74.56%. Two participants were removed from further analysis because their performance was below 50%. These participants presented a general lower recognition of the electrical stimulation. This might be related with body impedance, or body fat distribution. Even though the participants claimed their ability to recognize the stimulation, the performance evaluation presented negative results. This problem might be solved by controlling the current flowing through the body of the person producing better localized signals. ANOVA tests showed no influence from the stimulation direction nor the side. Patterns in the other hand did show influence on performance, with only duty rate patterns (20% and 40%) performing below the 75% recognition rate threshold. These results show promise to transmit reliable gradual proprioceptive information to prosthetic devices users.

5. Conclusions

In this study, we induced the apparent moving sensation on the lower back of 16 participants. We confirmed the possibility to produce the apparent moving sensation by simultaneously changing the stimulation intensity. We achieved a 74.56% recognition rate, however, not all patterns meet the 75% recognition threshold. Future work will be directed in improving the recognition rate for smaller increments of duty rate.

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